

A Suggestion to Make Gurson Damage Model Mesh Independent Numerically

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1. ABSTRACT

Continuum damage mechanics is applied to compute fracture J-initiation and J-Resistance (J-R) curve for 20MnMoNi55 material by analyzing TPB and CT specimens. A strong mesh dependency of Gurson model is observed. The exponential form of q_2 parameter shown by Dutta (2008) near crack tip is further modified to have a variable asymptotic value q_{2a} away from crack tip. The asymptotic value q_{2a} is suggested to be a function of crack-tip mesh size to overcome mesh dependency of J-R and load-displacement curves. The relation between q_{2a} with the normalized crack-tip mesh size is determined numerically for CT and TPB specimens.

2. INTRODUCTION

Micro-mechanical modeling of material damage helps to overcome some of the inherent limitations of conventional fracture mechanics. A number of models exist within the frame work of micro-mechanical modelling which address various phenomena of material behavior during material damage ranging from ductile to cleavage fracture. The ductile rupture follows the nucleation, growth, and coalescence of microvoids with significant plastic deformation. This consumes much more energy due to plastic deformation. The modelling is done using two independent methodologies. The model of Rice & Tracey for ductile crack initiation is based on a critical cavity growth. Attempts were made earlier to make such models mesh independent (Dutta, 2004,2005). The "coupled" constitutive models of Gurson and Rousselier affect the yield behavior. The specific material subroutines are required to perform FE analysis. In order to account for the effects of void nucleation and coalescence, and to obtain better agreement between the experimental results and numerical simulations, the original Gurson model was modified and extended into a semi-phenomenological form. The material input parameters of the micro-mechanical models should be obtainable from metallurgical observations. However, the determination of damage parameters is still predominantly a phenomenological fitting procedure and is done by combining test results and numerical simulations.

3. EXPONENTIAL VARIATION OF q_2 PARAMETER NEAR CRACK TIP

Dutta (2008) presented J-initiation and J-Resistance (J-R) curve for carbon steel materials using Gurson model. A difficulty was experienced to obtain a set of Gurson parameters which can compute J-initiation as well as entire J-R curve close to the measured values. It was then shown that a phenomenological form of q_2 parameter of Gurson constitutive model helps to overcome this difficulty. The new form of q_2 has an exponential spatial variation near the crack tip and has two-constants.

$$q_2 = 1 + q_{2a} e^{-q_{2b}\rho} \quad \text{Where, } \rho = \frac{r}{l_c} \quad (1)$$

Here 'r' is the distance from crack tip and l_c is the critical length of Gurson model. The appropriate choice of additional constants q_{2a} and q_{2b} help analysts to compute complete J-R curve (including J-initiation) close to experimental data. The same set of constants was also found to be useful for other fracture specimens and materials.

4. MESH INDEPENDENT STUDIES ON TPB SPECIMEN

During the present study, an attempt has been made to overcome mesh dependency of the Gurson model by using exponential form of parameter q_2 described above. The analysis has been first carried out on TPB specimen made up of 20MnMoNi55 material. Figure 1 shows the schematic diagram of the specimen along with the finite element mesh. Figure 2 shows the engineering stress-strain curve for 20MnMoNi55 material and Table-1 shows the Gurson parameters used in the present analysis.

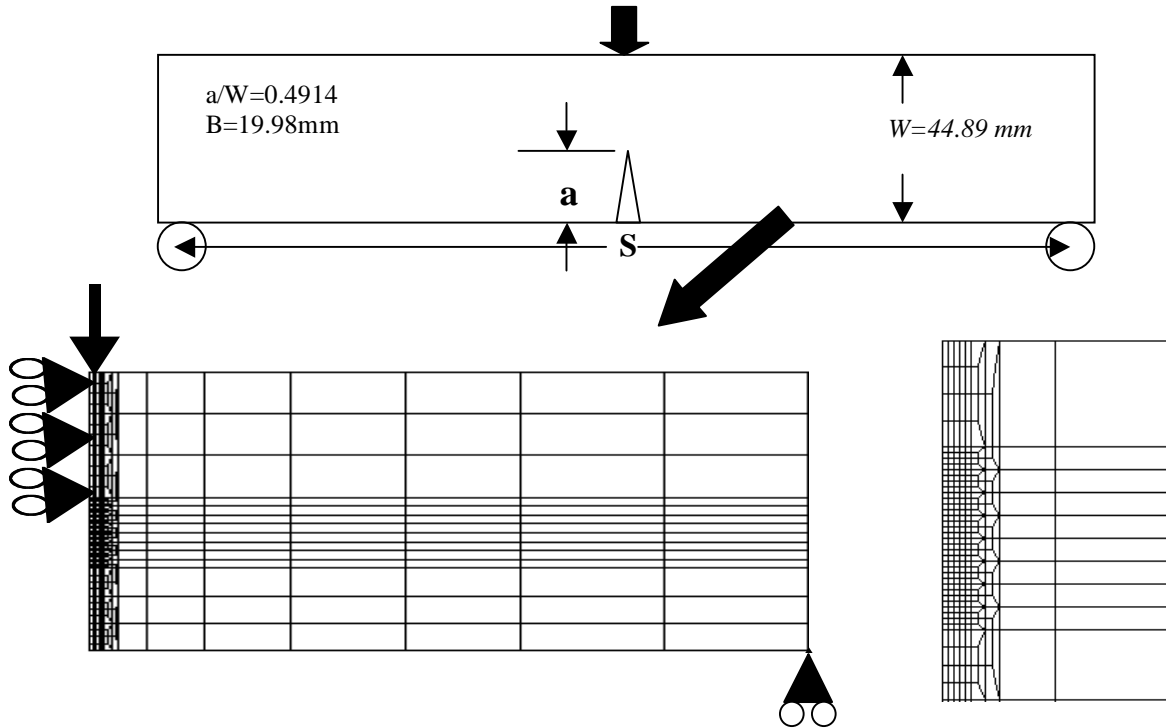


Fig. 1 Finite Element mesh of TPB specimen along with zoomed view of crack tip region

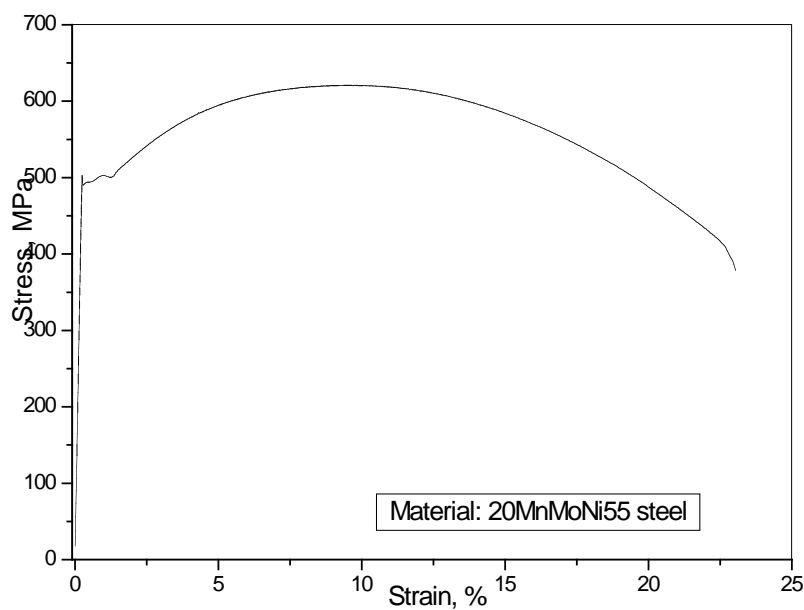


Fig. 2 Engineering stress-strain curve of 20MnMoNi55 steel material

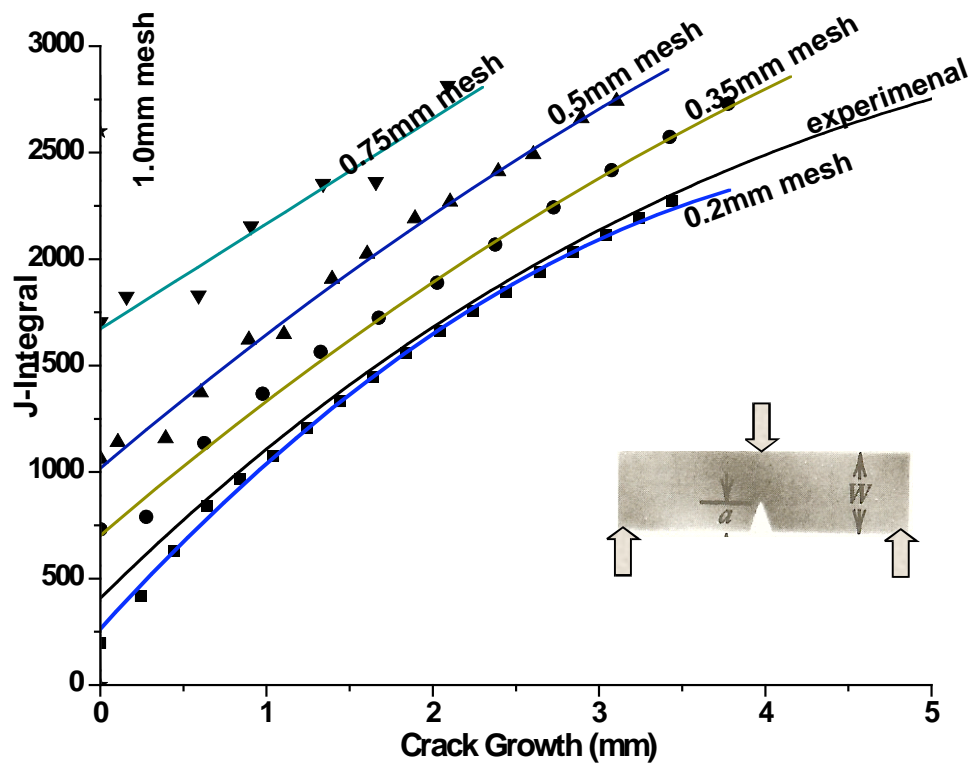


Fig. 3 Mesh dependency of J-R curve computed using Gurson model for a TPB specimen

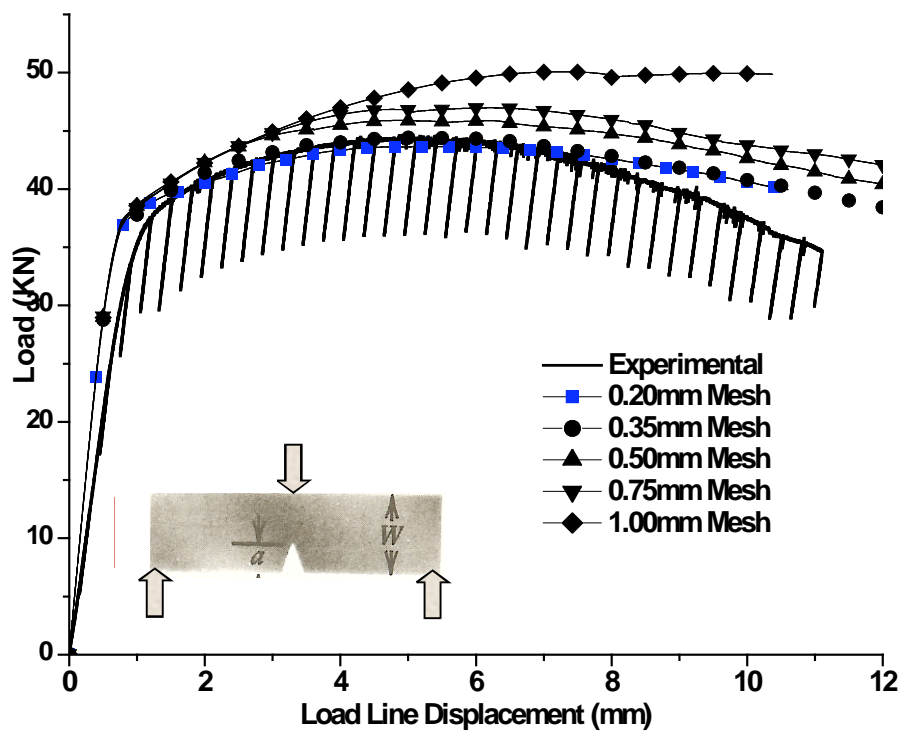


Fig. 4 Mesh dependency of load-displacement curve computed using Gurson model for a TPB specimen

Table-1. Gurson parameters for 20MnMoNi55 material

f_0	f_c	f_f	f_n	S_n	ϵ_n	q_1	q_2			q_3	l_c
							q_{2a}	q_{2b}	q_{2c}		
1.0^{-5}	0.05	0.3	0.002	0.1	0.3	1.5	1.0	0.3	1/6	2.25	0.1

Various sizes of crack tip elements ranging from 0.2×0.2 mm to 1.0×1.0 mm are employed. Figure 3 shows the J-R computed for various sizes of crack-tip mesh. Figure 4 shows the corresponding load-displacement curves. A strong mesh dependency of J-R and load-displacement curves may be seen in these figures. Various alternatives were tried to reduce mesh dependency numerically. The most viable alternative has been found to be the modification of asymptotic value of q_2 away from crack tip in (1). For this purpose, the eq. (1) is modified as follows.

$$q_2 = q_{2a} + q_{2b} e^{-q_{2c} \rho} \quad (2)$$

In this new form, the asymptotic value away from crack tip is q_{2a} . To achieve mesh independency, different values of q_{2a} were tried for various sizes of crack-tip mesh.

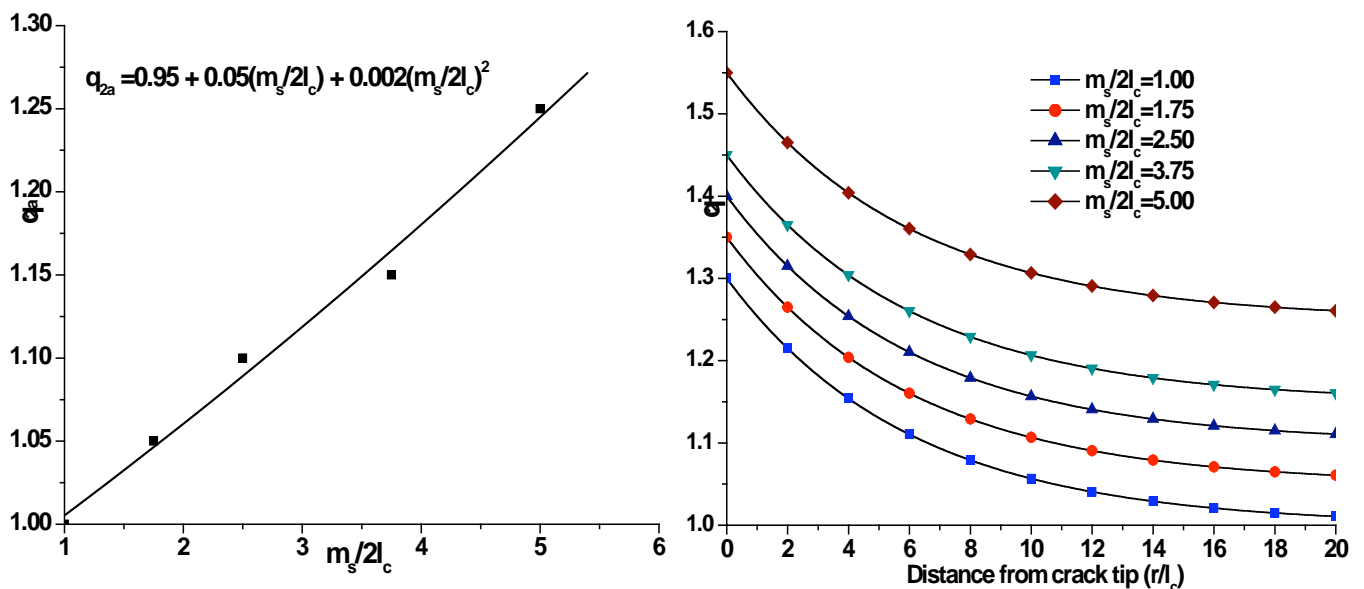


Fig. 5 Variation of q_{2a} and corresponding q_2 near crack tip for mesh independency in TPB specimen

Figure 5 shows the variation of q_{2a} with the normalized crack-tip mesh size for which reasonable mesh independency is achieved for the crack-tip mesh size ranging from 0.2mm to 1mm. The same figure also shows the variation of q_2 near tip. Figure 6 shows the J-R curves and Fig. 7 shows the load-displacement curves computed using the value of q_{2a} shown in Fig. 5. It may be seen that a reasonable mesh independency is achieved using such variation of q_2 . Fig.8 shows the improvement in J-R curves for each mesh size separately by using such variation of q_2 .

5. MESH INDEPENDENT STUDIES ON CT SPECIMEN

The above exercise is then repeated for a CT specimen made up of 20MnMoNi material. Fig. 9 shows the schematic diagram of the specimen with salient dimensions. The finite element mesh near the crack tip is also shown in the same figure.

Various sizes of crack tip elements ranging from 0.2×0.2 mm to 1.0×1.0 mm are employed. Figure 10 shows the computed load-displacement and J-R curves. A strong mesh dependency of J-R and

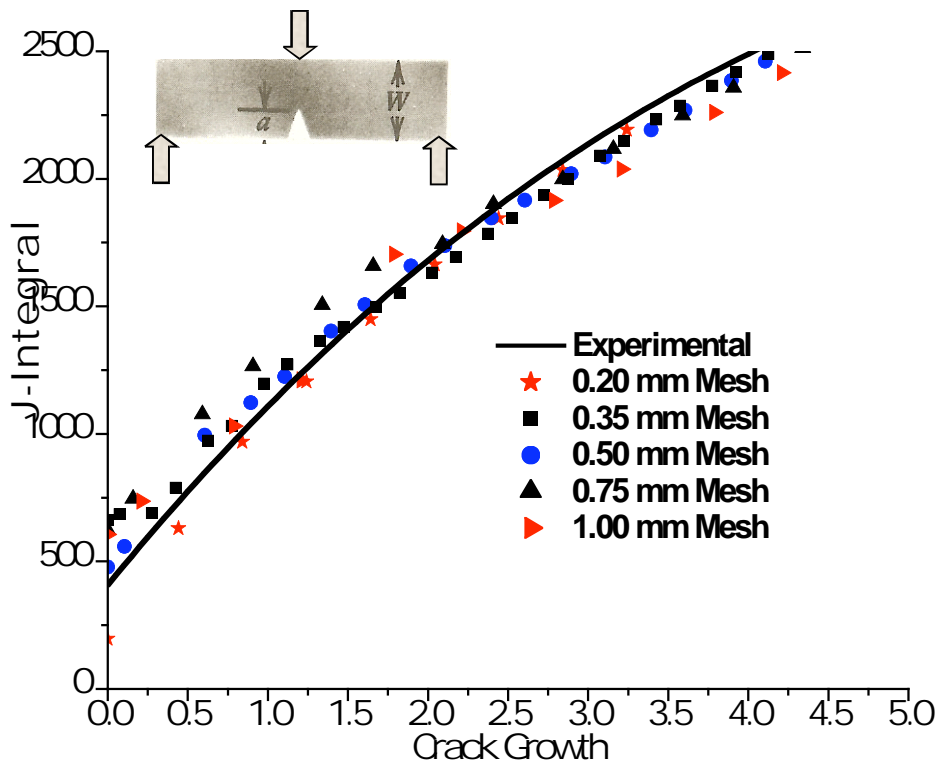


Fig. 6 Mesh independent J-R curves for various sizes of crack-tip elements using appropriate values of q_{2a}

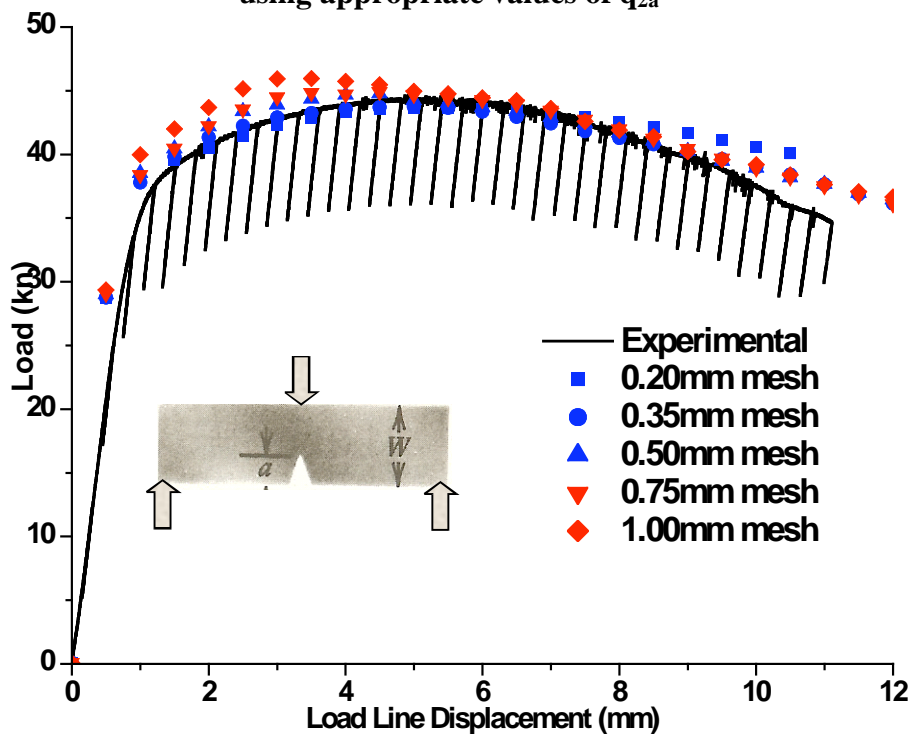


Fig. 7 Mesh independent load-displacement curves for various sizes of crack-tip elements using appropriate values of q_{2a}

load-displacement curves may be seen in these figures. The modified form of q_2 shown in eq. 2 has been then employed to overcome mesh dependency. Fig. 11 shows the variation of q_{2a} employed for this purpose. Fig. 12 shows the load-displacement and J-R curves obtained by using this variation of q_{2a} for various sizes of crack tip mesh. A reasonable mesh independency may be seen in this figure.

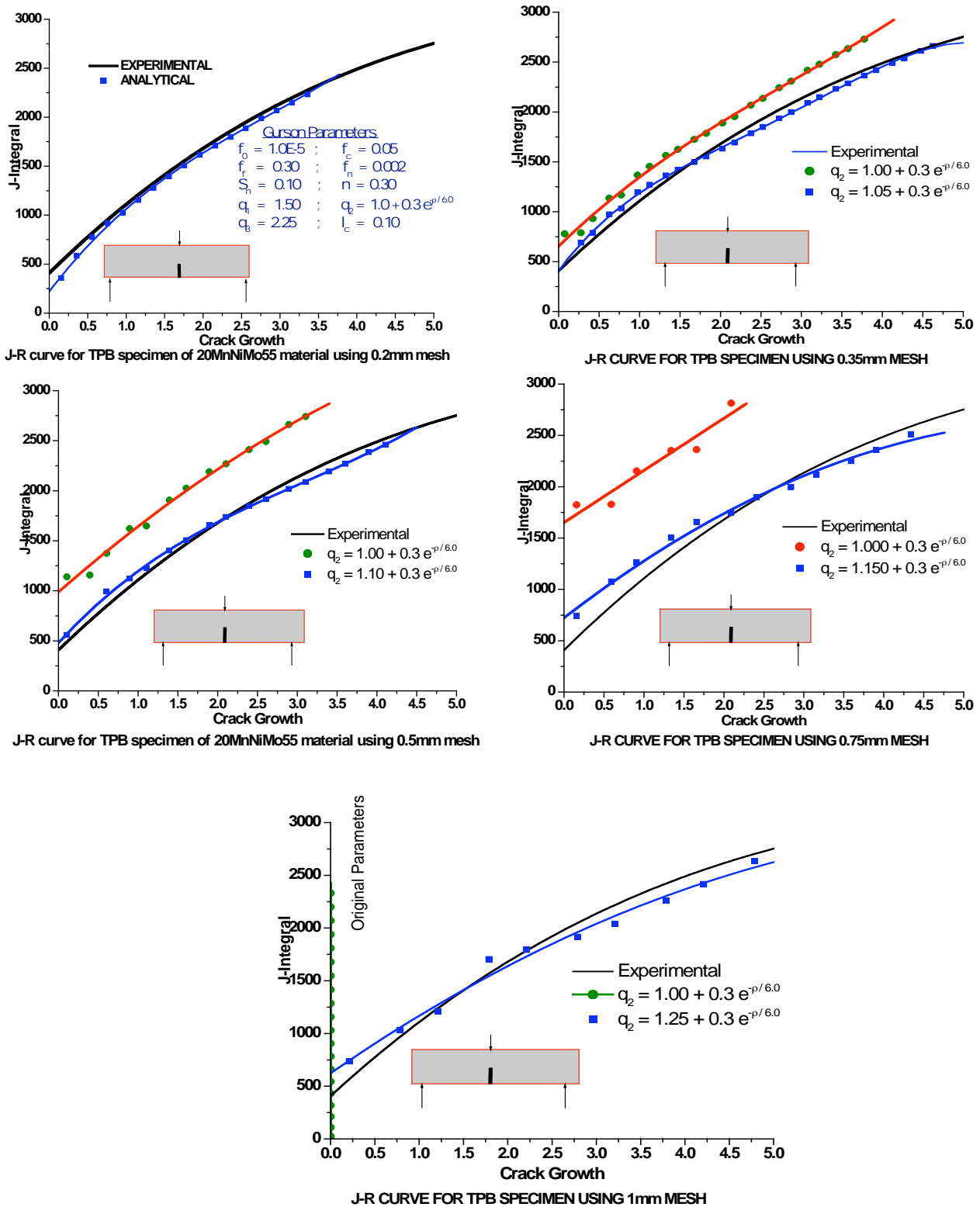


Fig. 8 J-R curves of TPB specimens for various sizes of mesh using modified form of q_2

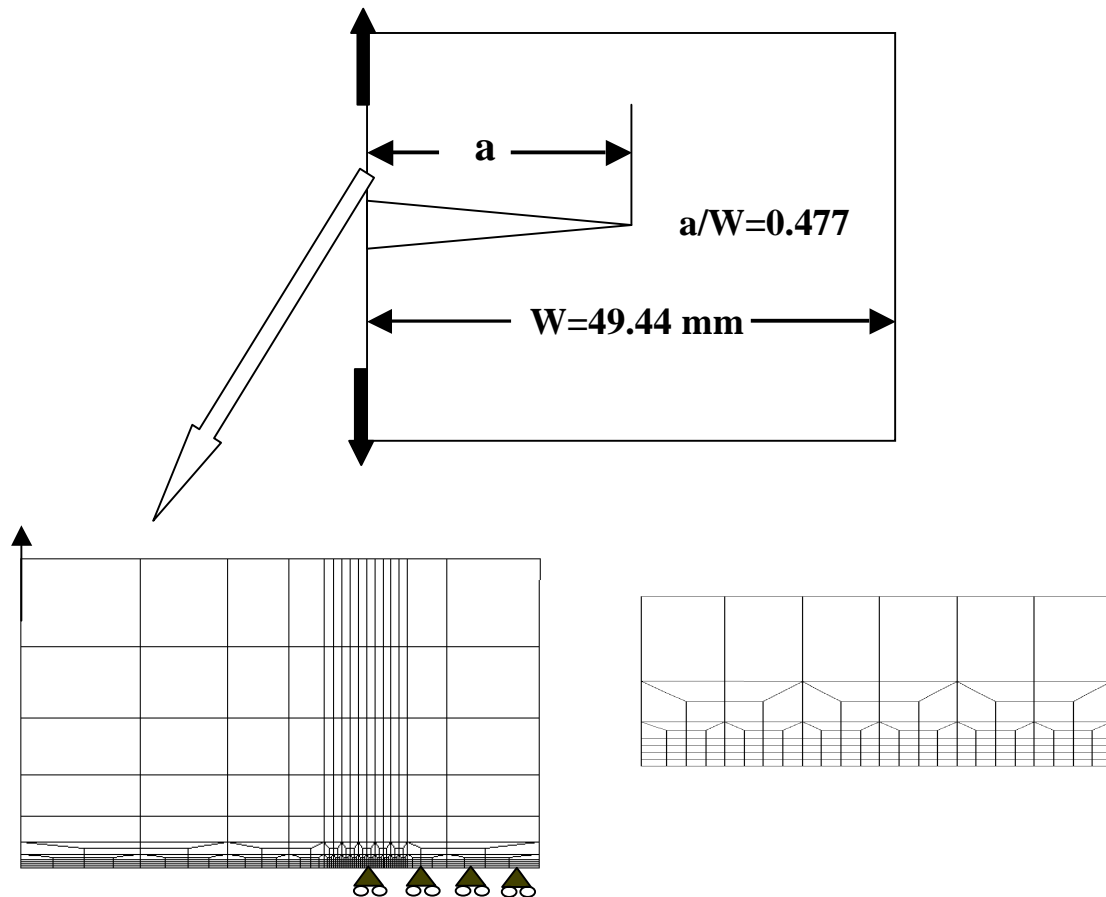


Fig. 9 Schematic diagram of CT specimen with zoomed view of finite element mesh

6. CONCLUSIONS

The following conclusions may be drawn from the present study.

1. A strong mesh dependency is seen while computing J-initiation and J-R curve of fracture specimens using Gurson model.
2. A new phenomenological form of q_2 parameter suggested earlier (Dutta, 2008) is then further modified to have a mesh dependent asymptotic value q_{2a} away from crack tip.
3. The new form is then used to analyze TPB specimen for various sizes of crack tip elements. A variation of q_{2a} with mesh size is determined which can compute mesh independent load-displacement and J-R curves.
4. The similar exercise is then repeated for a CT specimen.
5. It is expected that, the new form of q_2 will help the analysts to compute mesh independent J-R curve and load-displacement curves while using Gurson model.

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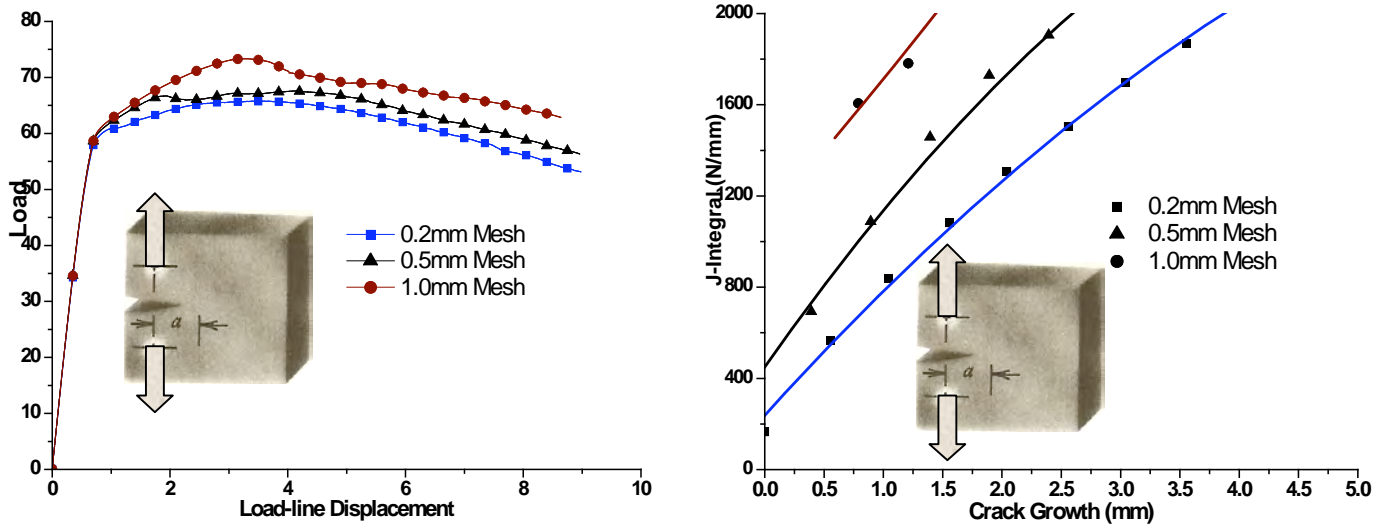


Fig. 10 Mesh dependency of load-displacement and J-R curves for a CT specimen

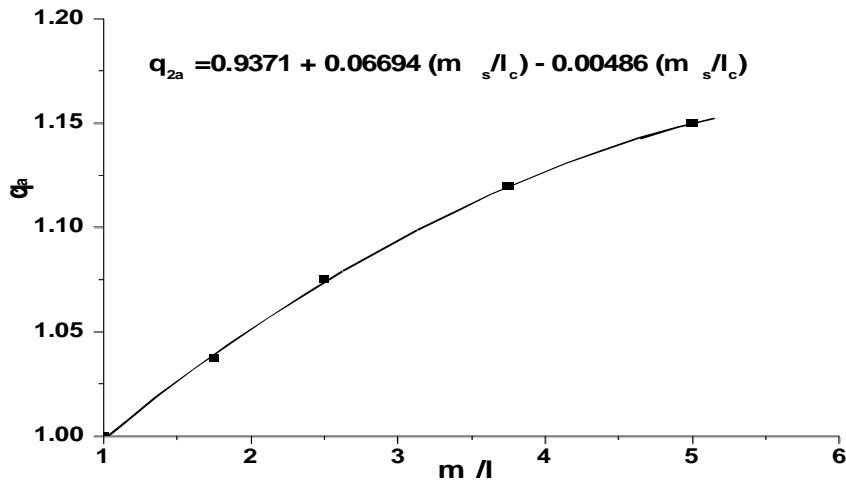


Fig. 11 Variation of q_{2a} for mesh independency in CT specimen

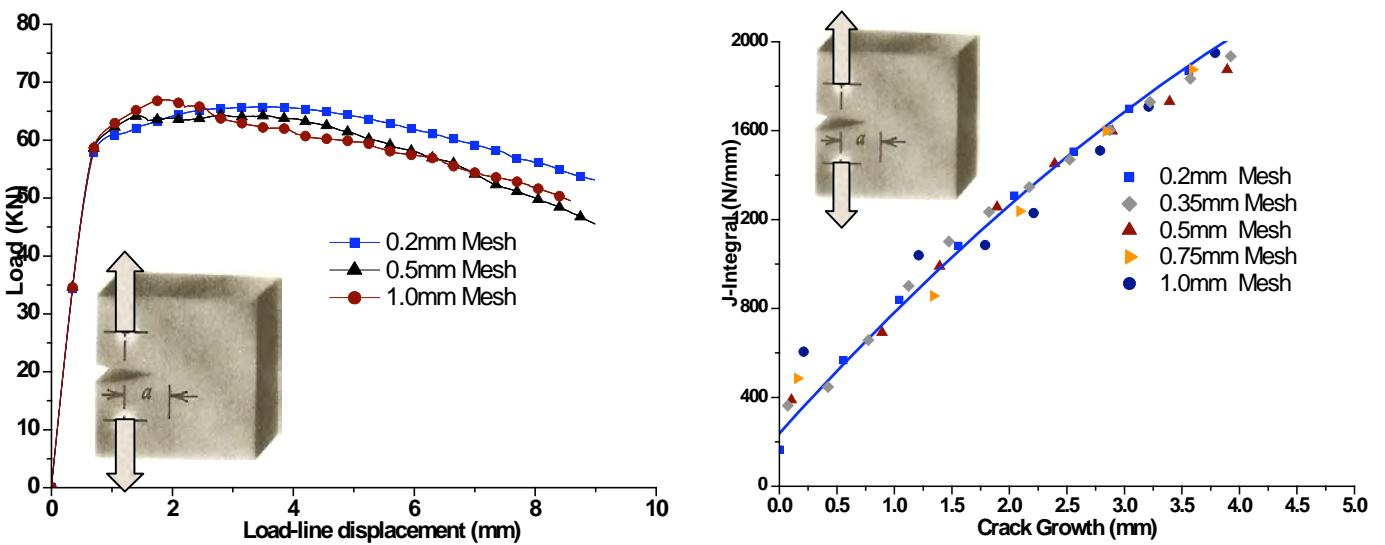


Fig.12 Mesh independent load-displacement and J-R curves for CT specimen